# LABORATORY OF PLASMA STUDIES

Potential Measurements of an Intense
Pulsed Ion Beam

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LPS 339 October 1984

N00014-83-K-2059



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## ABSTRACT

Potential measurements have been made on an intense proton beam with a capacitive voltage monitor. Beam potential as a function of position and diode voltage exhibit characteristics which can be explained by 1-D theory and simulation. The capacitive monitor causes a minimal pertibation of the beam potential. Discrepancies with theory can be explained by the violation of the cold electron source assumption. The potential measurement have been corroborated with ion current density measurements made with a biased charge collector. The data indicates a large thermal spread for the comoving electron velocity distribution.

For successful vacuum propagation of intense ion beams into a field free region, electron neutralization is essential. If a source of electrons is accessable to an ion beam, the space charge of the beam will draw the highly mobile electrons into the beam. It is found that under these conditions the ion beam can propagate charge and current neutralized.

Humphries one dimensional analysis of the charge and current neutralization of an ion beam by an infinite source of cold electrons ($KT_e << \frac{1}{2} m_e V_i^2$, where $V_i$ is the ion velocity) at x=0 predicts;

(1) A sheath developes between x=0 and

$$x = x_s = 4 \quad \frac{\left(\frac{1}{2} m_e V_i^2\right) \varepsilon_o \; 1/2}{n_i e^2} \tag{1}$$

$x_s \approx .2$cm (typical experimental value).

(2) The potential increass from $\phi = 0$ at $x = 0$ to

$$\phi = \phi_s = \frac{1}{2} m_e (2V_i)^2 / e \tag{2}$$

at $x = x_s$ and remains constant dropping to zero at the beam head.

(3) Electrons are accelerated to $2V_i$ in the sheath region with a density of $n_i/2$. The electron current density is $en_iV_i$ which equals the ion current density.

(4) As the electrons travel through the beam and reach the sheath at the beam head they are reflected to a final velocity of zero with a density of $n_i/2$. The net electron density is $n_i$ which equals the ion density. The resulting beam potential, velocity distribution, and density distribution is shown in Figure 1.

It is evident that the resulting velocity distribution is highly unstable to a two stream instability between the 0, 2Vi electrons. The thermalizing effects of the two stream instability has been investigated by Humphries et al.[2] with a computer simulation yielding the following results;

(1) Early in time the sheath width and peak potential are in agreement with eqn (1) and (2) (Figure 2a).

(2) Later in time, when the ions have moved more then a few sheath widths, the downstream electron distribution is thermalized. The sheath width has broadened and the peak potential has risen to appox. $\frac{1}{2} m_e (2.6V_i)^2/e$. (Figure 2a)

(3) Downstream the potential drops to a constant value of $\frac{1}{2} m_e V_i{}^2/e$. (Figure 2a)

(4) The final electron velocity distribution has an average value of $V_i$ with a thermal spread of approx .6Vi. (Figure 2b).

To study the neutralization mechanism potential measurements were made on a pulsed intense proton beam. The beam was extracted from a racetrack type magnetically insulated diode (figure 3) with the following parameters;

1. A-K gap = .9 cm
2. 315 kV $\leq V_d \leq$ 420 kV (inductively corrected, peak)
3. $B_{insulating}$ = 7 kG.
4. Drilled polyethylene anode (129 $cm^2$, .5 mm holes on a .25cm x .25cm grid).

Typical voltage, current, and ion current density traces are shown in figure 4.

As the beam is extracted from the diode, neutralizing electrons are drawn from either the drifting $\underline{E} \times \underline{B}$ electron cloud or from secondaries produced by the protons striking the aluminum vanes in the cathode. In the metal vacuum vessel (Figure 3) stray electric and magnetic fields generated by the large diode currents violates the assumption of the beam propagating into a field free region. To eliminate this problem the beam was allowed to exit the metal vacuum vessel through a hole in the wall where a 175 gauss transverse magnetic field was applied to strip off the neutralizing electrons. Immediately after the transverse field a 30 x 30 strands per inch grounded copper screen was placed in the beam path to serve as a localized source of new neutralizing electrons. (Figure 3). Once through the screen, the beam propagated into a field free Pyrex tube where the potential measurements were made. No sources of electrons were supplied past the screen.

The potential measurements were made with the capacitive voltage divider shown in Figure 5. The probe was constructed from .086" outer diameter, 50 Ω, semirigid coax. A section of the outer conductor was strippd off and this portion of the probe was placed in the beam channel. The capacitance per unit length of the coax is known therefore the capacitance between the center conductor and the beam is simply a function of the length of the stripped coax section as long as the stripped section is in the beam channel. The unstripped coax section serves as the second capacitor of the voltage divider and the divided voltage is measured with a parallel resistor chain. A typical oscilliscope trace and the equivalent circuit are shown in figure 5.

The results of the potential measurements as a function of axial position are shown in Figure 6a. The potential near the screen is $\frac{1}{2} m_e (2.6V_i)^2/e$, in agreement with the value predicted by the computer simulation. Downstream the potential decreases to a constant value. The rate at which the potential decreases is slower and the final value of $\frac{1}{2} m_e (1.7V_i)^2/e$ is higher then predicted by the computer simulation.

The downstream discrepancy can be explained by the fact that the neutralizing electrons supplied at the screen may not be cold. These electrons are secondaries produced by collisions between the proton beam and the screen and the condition $KT_e << \frac{1}{2} m_e V_i^2$ is possibly violated. If this is indeed the case the two stream instability growth rate would be smaller and the potential would not decrease as rapidly as predicted by the computer simulation. The downstream electrons would also be hotter (higher potential) due to the additional thermal energy aquired at the screen.

A second series of potential measurements were made near the screen for various diode voltages between 315 kV and 420 kV. (Figure 6b). The potential was found to be very close to $\frac{1}{2} m_e (2.6V_i)^2/e$ over the entire operating range. Null shots were also taken where the beam was blocked from the probe and these shots yielded no signal pick-up.

In conclusion, a capacitive voltage divider has been used to make potential measurements on a pulsed intense proton beam. The results agree in many respects with a previous computer simulation of the neutralization process. Downstream discrepancies can be explained by the fact that the cold electron assumption in the computer simulation may be violated in the experiment.

## Acknowledgement

This work supported by the Office of Naval Research.

## REFERENCES

1. S. Humphries Jr. Appl. Phys. Lett. 32, (12), 15 June 1978.

2. S. Humphries Jr., T.R. Lockner, J.W. Poukey and J.P. Quintenz Phys. Rev. Lett. Volume 46, Number 15 , 15 April 1981.

# CONCLUSIONS

1. Potential measurements have been made on an intense pulsed ion beam with a capacitive monitor.

2. Potential measurements in general agreement with one dimensional theory and simulation.

3. Violation of the cold electron source assumption in the experiment could explain deviation from the one dimensional theory.

4. Potential measurements indicate a large thermal spread in the comoving electron velocity distribution.

5. Thermalized comoving electrons explain unbiased charge collector signal.

6. Biased charge collector measurements verify electron velocity distribution infered from the potential measurements.